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Hip joint moments in symptomatic vs. asymptomatic people with mild radiographic hip osteoarthritis

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ABSTRACT

Our primary objective was to examine external hip joint moments during walking in people with mild radiographic hip osteoarthritis (OA) with and without symptoms and disease-free controls. Three groups were compared (symptomatic with mild radiographic hip OA, n = 12; asymptomatic with mild radiographic hip OA, n = 13; OA-free controls, n = 20). Measures of the external moment (peak and impulse) in the sagittal, frontal and transverse plane during walking were determined. Variables were compared according to group allocation using mixed linear regression models that included individual gait trials, with group allocation as fixed effect and walking speed as a random effect. Participants with evidence of radiographic disease irrespective of symptoms walked 14–16% slower compared to disease-free controls ($p = 0.002$). Radiographic disease without symptoms was not associated with any altered measures of hip joint moment compared to asymptomatic OA-free controls once speed was taken into account ($p \geq 0.099$). People with both mild radiographic disease and symptoms had lower external peak hip adduction moment ($p = 0.005$) and lower external peak internal rotation moment ($p < 0.001$) accounting for walking speed. Among angular impulses, only the presence of symptoms was associated with a reduced hip internal rotation impulse ($p = 0.002$) in the symptomatic group. Collectively, our observations suggest that symptoms have additional mechanical associations from radiographic disease alone, and provide insight into potential early markers of hip OA. Future research is required to understand the implications of modifying walking speed and/or the external hip adduction and internal rotation moment in people with mild hip OA.

1. Introduction

Modifiable treatment targets for hip osteoarthritis (OA) have not been definitively identified, and treatment effects of conservative treatments such as exercise are at best modest (Fransen et al., 2014). Hip joint loading could be an important treatment target to alleviate symptoms (Solomonow-Avnon et al., 2017) and preserve the integrity of the hip joint (Tateuchi et al., 2017). Hip joint loading during walking is poorly understood in people with early or mild hip OA and there is often discordance between radiographic evidence of hip OA and hip related pain (Kim et al., 2015). Understanding if surrogate measures of hip joint loading differ according to symptoms during walking in people with mild radiographic disease could help better understand pathophysiology and inform therapeutic treatments.

The external peak hip flexion moment and peak hip adduction moment are of interest given that both account for a substantial proportion of total hip joint contact force during walking (Wesseling et al., 2015). Meta-analyses indicate that people awaiting total hip replacement have lower peak external flexion moments and lower peak external hip adduction moments joint during walking compared to controls, while those with less severe hip OA appear to have comparable magnitudes of hip moments compared to controls (Diamond et al., 2018). However, a large degree of heterogenity was noted between studies (Diamond et al., 2018). Several factors such as walking speed (Boyer et al., 2008; Lelas et al., 2003), radiographic disease severity (Ardestani and Wimmer, 2016) and symptom severity (Hall et al., 2018) influ-

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ence hip joint moments in people with hip OA. Faster walking speed typically increases external hip joints moments in all planes (Chehab et al., 2017). Disease severity appears to reduce external hip joint moments (Foucher, 2015), while those with moderate pain during walking reportedly have a higher external hip adduction moment compared to those with less severe pain during walking (Hall et al., 2018). Investigations of homogenous samples of people with hip OA are needed to provide further insight into surrograte measures of hip joint loading during walking.

The primary purpose of this study was to determine the effect of symptoms on hip joint moments, in people with mild radiographic hip OA. We hypothezied that taking walking speed into consideration, people with a combination of symptoms and radiographic hip OA would have lower hip external moments during walking, compared to people with radiographic hip OA without symptoms. The secondary aim was to test the hypothesis that those with a combination of radiographic disease and symptoms would exhibit lower external moments during walking compared to people without hip OA and pain-free.

2. Methods

2.1. Participants

An institutional review board approved motion analysis repository was queried to identify participants for this study. All participants had provided written informed consent for their data to be used in secondary analyses. For the present analysis, participants were required to have gait data and hip radiographs available in the repository. Bilateral hip radiographs were available for all participants and were graded by a single trained rheumatologist (NS) according to modified Kellgren-Lawrence (KL) grading system (Kellgren, 1963).

2.2. Participants grouped based on symptomatic and radiographic status

Participants were divided into three groups: (i) symptomatic hip OA (participants with both hip pain and KL grade 2 radiographic hip OA); (ii) asymptomatic hip OA (participants without hip pain and with KL grade 2 radiographic hip OA) and (iii) control participants (without hip pain and KL grade 0 radiographic hip OA). Radiographs were acquired within one week of gait analysis.

Participants with symptomatic hip OA were a subset of participants reported in a previous study (Shakoor et al., 2014). Hip OA was classified according to the American College of Rheumatology criteria (Altman et al., 1991). Only participants with hip OA classified as KL grade 2 (definite narrowing of joint space inferiorly, definite osteophytes and slight sclerosis) (Kellegren, 1963) in either hip, were included in the symptomatic hip OA group. Hip pain severity was assessed using a visual analogue scale during screening, prior to gait testing. Participants were classified as symptomatic if pain was >30/100 mm in the hip with radiographic hip OA. Pain in the contralateral hip was required to be <30/100 mm on a visual analogue scale.

Asymptomatic participants with radiographic hip OA (KL grade 2) and asymptomatic radiographic OA-free controls were extracted from an existing lab database. Participants were eligible for inclusion in the database if no pain or functional impairment related to their hips and knees had been reported just immediately prior to gait testing. The Harris Hip Score (Harris, 1969) and Knee Society Score (Insall et al., 1989), were used to assess pain and function related to hips and knees, respectively. Participants with maximum values (i.e. no pain or functional impairment) were eligible and a randomly selected hip was used for gait analysis. Radiographs were taken on the day of the gait analysis. Participants were assigned to the asymptomatic hip OA group if either hip had a KL grade of 2. Participants were assigned to the OA-free asymptomatic control group if both hips had a KL grade of 0.

2.3. Gait analysis

Gait analysis was conducted using standard methods described in detail elsewhere (Andriacchi, 1990; Foucher et al., 2012; Hurwitz et al., 1998). Briefly, reflective markers were placed along bony landmarks of the leg. Markers at the head of the 5th metatarsal, lateral malleolus, calcaneus, lateral knee joint line, greater trochanter, and iliac crest were used to identify the proximal and distal ends of the segments. Anthropometrics were used to identify joint centers. Knee joint centers were determined by bisecting the distance between the joint lines on the medial and lateral side of the knee, which was measured with callipers. Ankle joint centers were similarly determined by bisecting the distance between the medial and lateral malleoli. The hip joint center was identified as a point 2.5 cm inferior to the midpoint of a line connecting the anterior-superior iliac spine and the pubic tubercle (Andriacchi, 1995). Participants walked at a range of self-selected speeds (preferred speed, slow, and fast) along a 10 m walkway. 5 to 16 trials (median 8) were available per participant. An optoelectronic camera system was used to record the position of the markers (Qualisys AB, Gothenberg, Sweden). A multicomponent force plate (Bertec, Columbus, OH, USA) was used to record the location and magnitude of the ground reaction force. Camera data were collected at 120 Hz. Force plate data were collected at 1200 Hz and down-sampled to align with camera data. Customised software (Computerised Functional Testing Corporation, Chicago, IL, USA) was used to calculate external moments about the hip using inverse dynamics using force and joint center data in conjunction with the inertial properties of the segments. The variables of interest included the peak external moments and angular impulses in the sagittal, frontal, and transverse planes. Variables were normalized to body weight and height (%bwht).

2.4. Statistical analysis

One-way ANOVA was used to assess differences in group demographic and physical characteristics as well as preferred, fast, and slow walking speeds. A series of mixed-effects models were used to quantify the relationship of peak external moments to presence of radiographic disease and symptoms, using walking speed as a random factor. The mixed-effect model follows the following form:

$$Y = Xb + Zu + E$$

where Y is a vector of observed values, b is a vector of coefficients for fixed effects, u is a vector of coefficients for random effects, X and Z are matrices of observations of fixed (group) and random (speed) effects respectively, and E is the error term vector. Using this format, we can create a linear regression model relating variables that vary per-trial – in this case, speed and moment values, while accounting for variables that are constant for each participant – in this case, presence of OA. Using an intercept as well as the walking speed variable in the random part of the model allows each participant to have their own linear relationship within the sample population, in our case relating speed and gait variables. In this way we can account for individual variances in the relationship between walking speed and gait, trial by trial variance in walking speed, and the associated variance in gait variables, and predict the variance in gait variables accounted for by fixed group factors. Thus, mixed-effects models were created with radiographic disease and symptoms as fixed effects and speed as a random factor for the hip joint

external peak moments. The factor with the highest p-value was removed until a model with factors below p = 0.05 were left. This is a robust approach for participants with varying numbers of trials and can account for multiple sources and levels of variance in a single model. Stata version 14.2 (Statacorp, College Station, TX, USA) was used to perform statistical analyses.

3. Results

Participant characteristics and spatiotemporal measures according to pain severity during walking are presented in Table 1. Age, sex, height, body mass and body mass index were comparable across groups. Preferred walking speed was significantly slower in those with both symptomatic and asymptomatic radiographic hip OA, compared to the OA-free asymptomatic controls (Fig. 1). Fast walking speed was also significantly slower in radiographic hip OA groups compared to the OA-free asymptomatic group with a similar trend for slow walking speeds (Table 1).

Results of mixed-model analyses are presented in Tables 2 and 3. The external peak hip flexion moment, peak hip extension moment, peak hip abduction moment, or the peak hip external rotation moment were not predicted by either the presence of radiographic disease or the presence of symptoms, which indicates that these variables were not different across the three groups. This analysis also demonstrates that an apparent reduction in the peak flexion and extension moments in the asymptomatic hip OA group compared to the OA-free asymptomatic group seen in Figs. 2–5 is likely due to the reduced walking speed in the mild group. By contrast, the presence of symptoms was associated with a reduced peak hip adduction moment and reduced hip internal rotation moment ($p \leq 0.005$), which indicates that these variables were significantly different in the symptomatic group compared to the other two groups (Figs. 3–5). Among angular impulses, only the presence of symptoms was associated with a reduced hip internal rotation impulse (p = 0.002) in the symptomatic group compared to the other two groups (Table 3).

4. Discussion

In people with mild radiographic disease, there were two main findings. First, compared to OA-free asymptomatic controls, the peak hip adduction, peak internal rotation moment and internal rotation impulse were lower in those with symptomatic radiographic hip OA but not in those with asymptomatic radiographic hip OA. Second, compared to OA-free asymptomatic controls, walking speed was significantly slower in people with radiographic hip OA, irrespective of the presence of symptoms. Taken together, these findings suggest that reduced frontal and transverse plane loading is concurrent with hip OA related symptoms, rather than structural OA and reduced walking speed is an early indicator of structural hip pathology.

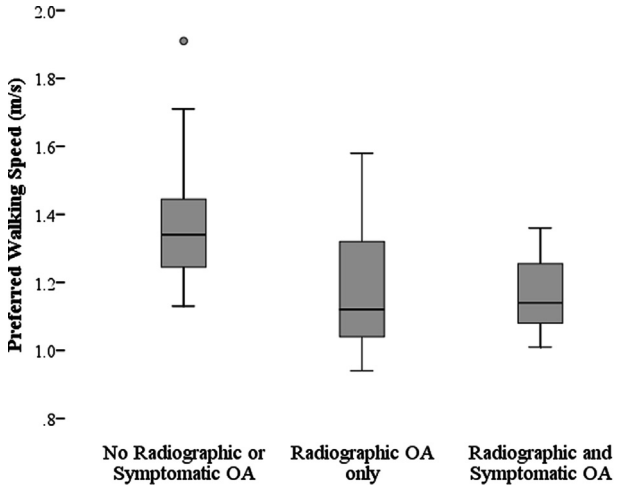

Fig. 1. Median (interquartile range) of walking speed according to group: (i) without radiographic hip osteoarthritis or symptoms; (ii) radiographic hip osteoarthritis only; (iii) radiographic and symptomatic hip osteoarthritis. The whiskers represent the 25th percentile and 75th percentile and circle represent outliers who exceed the 95th percentile.

A combination of symptoms and radiographic OA was associated with a reduced peak hip adduction moment and reduced internal rotation moment (peak and impulse) compared to controls, taking walking speed into consideration. These lower values imply reduced net demands on the hip abductor muscles and external hip rotators in the symptomatic hip OA group compared to the other two groups. However, it is unclear if the lower demands on the hip muscle groups are due to impaired hip muscle strength, size and/or altered muscle activation as previously reported in people with hip OA (Lawrenson et al., 2018; Loureiro et al., 2013; Rutherford and Hubley-Kozey, 2009). Our observation suggests however, that people with symptomatic hip OA, potentially adapt their gait strategy to reduce compressive forces of the hip abductors during walking. Several studies have linked frontal plane moments to hip joint contact forces (Foucher et al., 2009; Lenaerts et al., 2009; Schmidt et al., 2017; Wesseling et al., 2015). Lower loading may have implications for symptom alleviation in established disease. Further research is required to explore whether gait adaptations in those with a combination of symptoms and radiographic hip OA can be addressed using conservative interventions.

Our findings suggest that irrespective of the presence of symptoms, walking speed is slower in people with mild radiographic disease. Further to this, walking speed was not significantly different between the asymptomatic hip OA and symptomatic hip OA groups. Slower walking speeds are typically considered to be a manifestation of symptoms, rather than altered joint structure.

Table 1
Participant characteristics, mean and standard deviations unless otherwise stated.

	No radiographic disease	Mild radiographic osteoarthritis[†]		p value
	Asymptomatic (n = 20)	Asymptomatic (n = 13)	Symptomatic (n = 12)	
Female, n (%)	13 (65%)	11 (85%)	9 (75%)	0.455
Age, years	54 ± 7	53 ± 6	58 ± 10	0.280
Height, m	1.6 ± 0.1	1.6 ± 0.1	1.7 ± 0.1	0.228
Body mass, kg	72.5 ± 10.8	71.6 ± 10.6	81.4 ± 13.9	0.102
Body mass index, kg/m^2	26.8 ± 4.7	26.3 ± 3.0	28.4 ± 4.7	0.494
Preferred walking speed, m/s	1.39 ± 0.19	1.20 ± 0.20	1.16 ± 0.12	0.002
Self-selected fast walking speed, m/s	1.62 ± 0.25	1.43 ± 0.25	1.44 ± 0.14	0.029
Self-selected slow walking speed, m/s	1.10 ± 0.20	0.99 ± 0.19	0.94 ± 0.19	0.074

[†] Defined as Kellgren-Lawrence grade 2.

Table 2
Associations between hip external moments and radiographic and symptomatic osteoarthritis.

	Estimate (95% Confidence Interval)	p-value
Hip Flexion Moment (%bwht)		
Intercept	4.43 (3.90, 4.96)	<0.001
Level 2 (participant-specific)		
Radiographic OA	−0.08 (−0.89, 0.74)	0.854
Symptomatic OA	0.08 (−0.81, 0.96)	0.865
Hip Extension Moment (%bwht)		
Intercept	2.18 (1.83, 2.53)	<0.001
Level 2 (participant-specific)		
Radiographic OA	−0.05 (−0.60, 0.50)	0.852
Symptomatic OA	−0.01 (−0.61, 0.59)	0.979
Hip Abduction Moment (%bwht)		
Intercept	1.53 (1.25, 1.80)	<0.001
Level 2 (participant-specific)		
Radiographic OA	−0.04 (−0.47, 0.38)	0.837
Symptomatic OA	0.11 (−0.35, 0.57)	0.637
Hip Adduction Moment (%bwht)		
Intercept	4.04 (3.80, 4.28)	<0.001
Level 2 (participant-specific)		
Radiographic OA	X	X
Symptomatic OA	−0.67 (−1.12, −0.22)	0.005
Hip Internal Rotation Moment (%bwht)		
Intercept	0.80 (0.72, 0.88)	<0.001
Level 2 (participant-specific)		
Radiographic OA	X	X
Symptomatic OA	−0.29 (−0.44, −0.14)	<0.001
Hip External Rotation Moment (%bwht)		
Intercept	0.38 (0.30, 0.45)	0.000
Level 2 (participant-specific)		
Radiographic OA	0.10 (−0.02, 0.22)	0.099
Symptomatic OA	−0.11 (−0.24, 0.03)	0.113

Table 3
Associations between hip impulses and radiographic and symptomatic osteoarthritis.

	Estimate (95% Confidence Interval)	p-value
Hip Flexion Impulse (%bwht*s)		
Intercept	4.96 (3.95, 5.97)	<0.001
Level 2 (participant-specific)		
Radiographic OA	−0.09 (−0.99, 0.81)	0.857
Symptomatic OA	0.10 (−0.61, 0.81)	0.649
Hip Extension Impulse (%bwht*s)		
Intercept	2.48 (1.80, 3.16)	<0.001
Level 2 (participant-specific)		
Radiographic OA	−0.01 (−0.83, 0.81)	0.755
Symptomatic OA	0.02 (−0.81, 0.85)	0.769
Hip Abduction Impulse (%bwht*s)		
Intercept	1.96 (1.46, 2.46)	<0.001
Level 2 (participant-specific)		
Radiographic OA	−0.08 (−0.50, 0.34)	0.659
Symptomatic OA	0.12 (−0.22, 0.42)	0.499
Hip Adduction Impulse (%bwht*s)		
Intercept	3.39 (3.01, 3.77)	<0.001
Level 2 (participant-specific)		
Radiographic OA	−0.05 (−0.36, −0.26)	0.492
Symptomatic OA	−0.11 (−0.41, 0.19)	0.448
Hip Internal Rotation Impulse (%bwht*s)		
Intercept	0.53 (0.39, 0.67)	<0.001
Level 2 (participant-specific)		
Radiographic OA	X	X
Symptomatic OA	−0.23 (−0.42, −0.04)	0.002
Hip External Rotation Impulse (%bwht*s)		
Intercept	0.42 (0.34, 0.50)	<0.001
Level 2 (participant-specific)		
Radiographic OA	0.11 (−0.03, 0.25)	0.083
Symptomatic OA	−0.11 (−0.25, 0.01)	0.071

However, in the current study we observed that presence of symptoms does not appear to affect walking speed but rather it is the presence of mild radiographic disease. Perhaps slower walking speed is an early 'marker' of structural hip OA and participants unconsciously walk slower to avoid higher loads and/or potentially painful hip positions. However, it is important to acknowledge the cross-sectional nature of this study and consider that participants in the asymptomatic radiographic disease group, may have experienced symptoms prior to gait assessment and/learned to adjust their walking speed accordingly. The role of neuropathic pain is also increasingly considered in OA (Dimitroulas et al., 2014; McDougall and Linton, 2012) and widespread sensory deficits have been reported in people with hip OA (Shakoor et al., 2008). It is unknown whether people with hip OA and reduced walking speed should be encouraged to walk faster. Faster walking speed has been demonstrated to be a significant predictor of improved quality of life following a gait therapy intervention in people with hip OA (Solomonow-Avnon et al., 2017). However, it is possible that increasing walking speed would increase loading and may induce acute pain-flares, and/or be detrimental to the integrity of the hip joint structure.

The relationship between surrogate measures of joint loading and presence of symptoms is complex and appears to be joint specific. The current study supports the contention that hip OA symptoms are likely to lead to *lower* hip joint load, while in knee OA symptoms have been associated with *higher* measures of knee joint loading (Thorp et al., 2007). Our observations that the adduction moments and internal rotation moments were lower compared to controls in the symptomatic hip OA group only are line with findings in knee OA, but with opposite directions of moment magnitudes. Among people with mild radiographic knee OA (KL grade 2), those who were symptomatic had a higher knee adduction moment than those who were asymptomatic, while those who were asymptomatic did not differ to controls. Taken together, OA symptoms irrespective of structural disease, appears to be present with abnormal biomechanics. Although the implications of lower hip adduction moment on joint structure is unclear, preliminary evidence from a pilot study suggest that lower hip adduction moments are potentially associated with rapid disease progression in people with hip OA (Foucher et al., 2011).

In addition to joint specificity, greater pain severity has been associated with greater hip joint loading in people with hip OA (Hall et al., 2018). Conceivably, pain can lead to reduced hip joint loading, and lower joint loading can relieve joint pain. However, it remains unknown if people with mild hip OA, who are treated with exercise as first-line treatment return to 'typical' hip moment magnitudes in response to alleviation of pain. It is important to acknowledge that although the external hip adduction and rotation moments explain a substantial proportion of joint contact forces during walking (Wesseling et al., 2015), we cannot conclude from our investigation that hip joint contact forces are indeed lower. Muscles are a major contributor to hip joint contact force during walking (Correa et al., 2010). Future studies should account for muscle activations in hip joint contact force estimations using electromyography-driven musculoskeletal modelling to further understand hip joint loading by symptom severity.

The current study is the first to compare people with mild radiographic hip OA with, and without symptoms, to asymptomatic OA-free controls. Despite the paucity of studies investigating hip joint moments specifically in people with mild hip OA, some studies have found lower sagittal hip joint moment in people

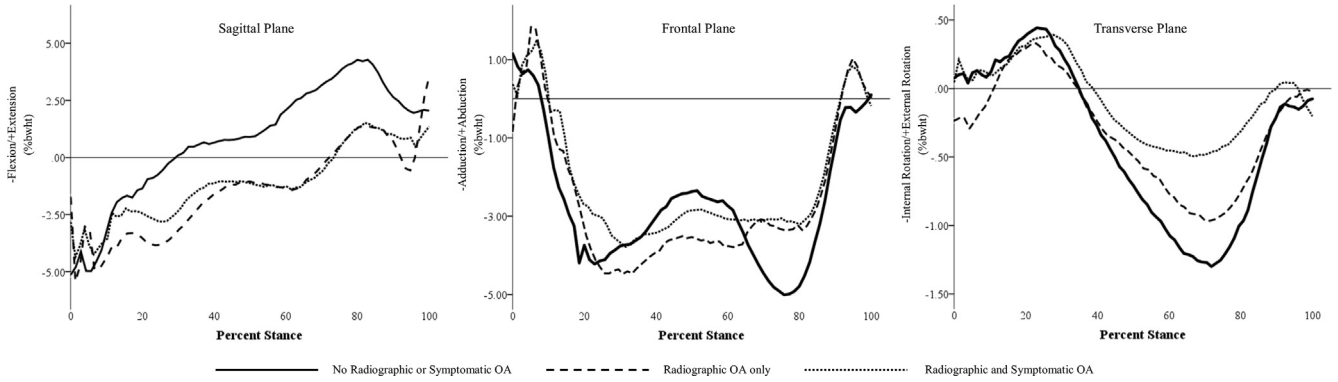

Fig. 2. Representative external moments for participants in each group. Trial selected represents walking at preferred speeds, participants selected represents a participant who walked at the mean preferred speed for each group.

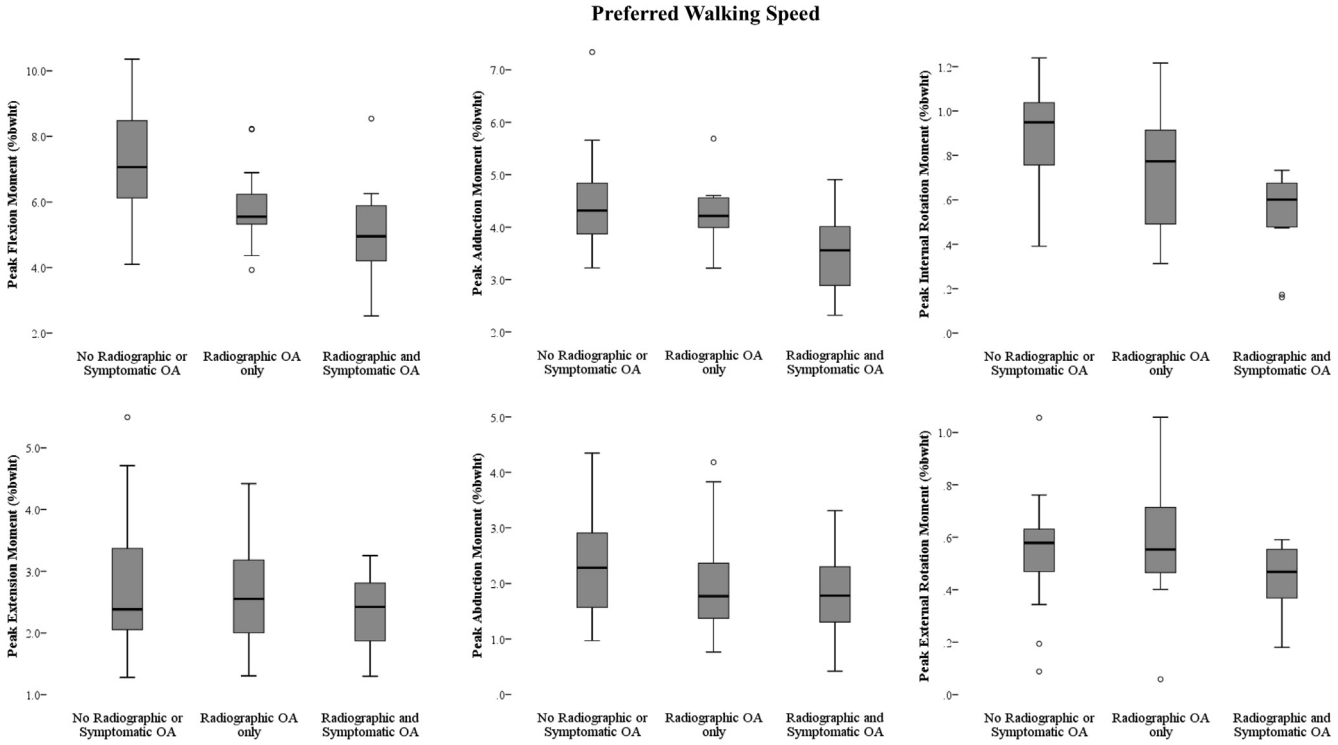

Fig. 3. Median (interquartile range) of external peak hip moments at preferred walking speed according to group: (i) without radiographic hip osteoarthritis or symptoms, (ii) radiographic hip osteoarthritis only; (iii) radiographic and symptomatic hip osteoarthritis. The whiskers represent the 25th percentile and 75th percentile and circles represent outliers who exceed the 95th percentile.

with hip OA compared to controls (Eitzen et al., 2012, 2015; Kumar et al., 2015), albeit inconsistently (Constantinou et al., 2017). Inconsistencies could be due to differences in the way that walking speed was handled in the experimental or statistical design, similar to inconsistencies in the relationship of the knee adduction moment to knee OA due to speed (Astephen Wilson, 2012). In the frontal plane, no difference between those with mild-to-moderate hip OA has been reported compared to controls (Constantinou et al., 2017; Kubota et al., 2007; Watelain et al., 2001) although again, inconsistently (Schmidt et al., 2017; Watelain et al., 2001). Frontal plane differences with control groups have often been found in end stage hip OA (Foucher, 2016; Foucher et al., 2007; Hurwitz et al., 1997; Meyer et al., 2018; Wesseling et al., 2018), but it is not clear when in the disease process this difference emerges.

Strengths of this study are the relatively homogenous sample of people with no or minimal radiographic hip OA (KL grade 0) or mild radiographic hip OA (KL grade 2). Moreover, to our knowledge this is the first study that includes a group of asymptomatic people with mild radiographic OA so that the role of symptoms can be evaluated separately from the role of radiographic changes. Limitations of the current study warrant consideration. First, different instruments were used to screen the asymptomatic (i.e. pain and physical function) and symptomatic groups (i.e. pain only). Thus, although patients with hip OA typically present with physical dysfunction, we cannot conclusively determine that the differences between asymptomatic group and symptomatic groups we exclusively due to pain. Second, we also acknowledge that the timing of symptom evaluation relative to gait assessment differed between groups. Third, interpretation of our observations is lim-

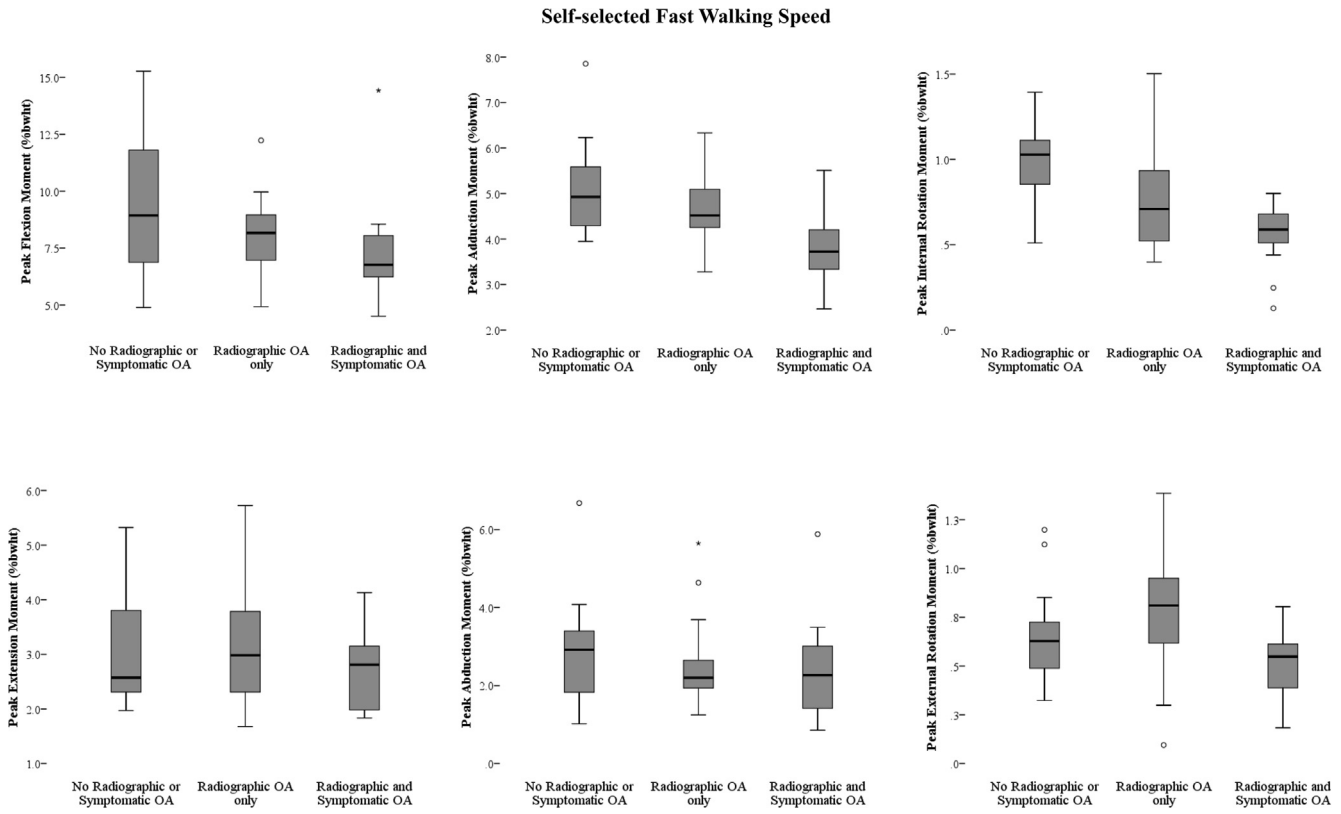

Fig. 4. Median (interquartile range) of external peak hip moments at fast walking speed according to group: (i) without radiographic hip osteoarthritis or symptoms, (ii) radiographic hip osteoarthritis only; (iii) radiographic and symptomatic hip osteoarthritis. The whiskers represent the 25th percentile and 75th percentile and circles represent outliers who exceed the 95th percentile.

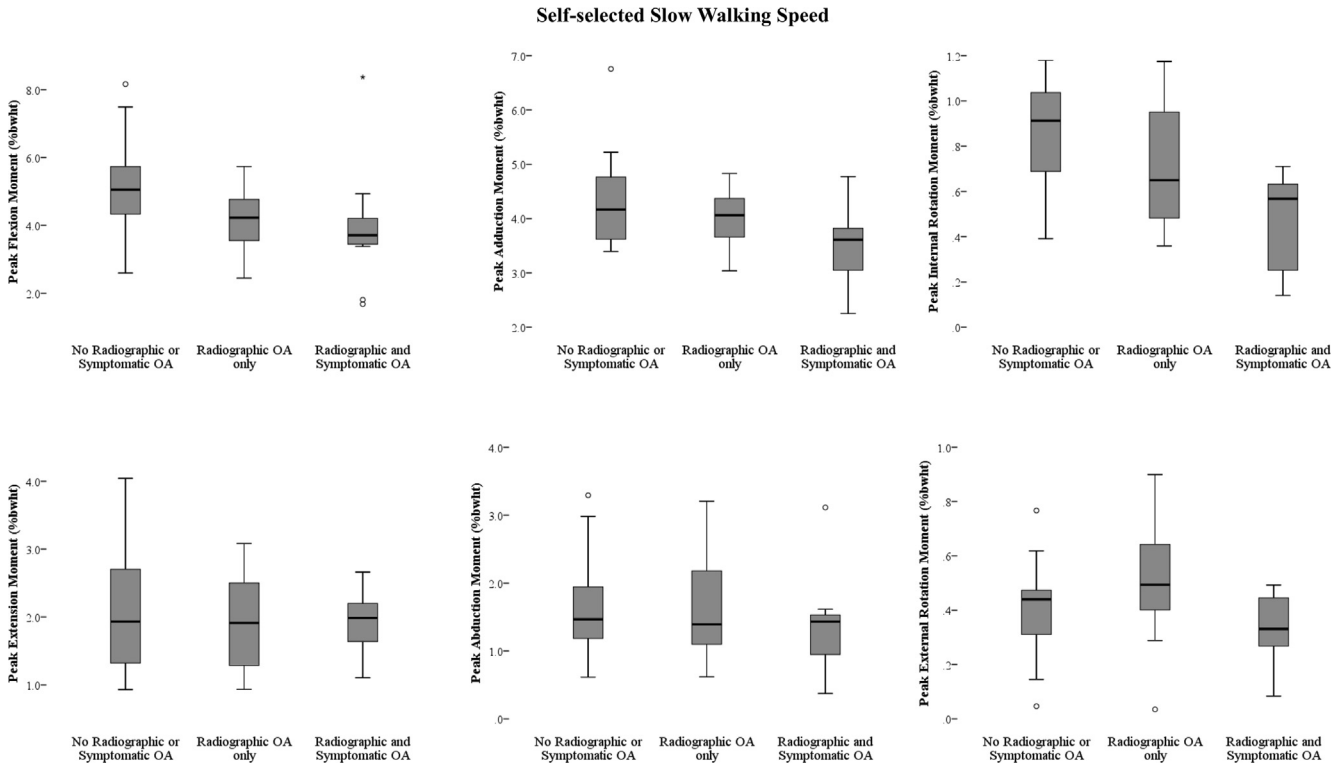

Fig. 5. Median (interquartile range) of external peak hip moments at slow walking speed according to group: (i) without radiographic hip osteoarthritis or symptoms, (ii) radiographic hip osteoarthritis only; (iii) radiographic and symptomatic hip osteoarthritis. The whiskers represent the 25th percentile and 75th percentile and circles represent outliers who exceed the 95th percentile.

ited by the cross-sectional design and the use of a convenience sample without *a priori* power analysis. Fourth, dynamic hip joint contact force cannot be readily assessed in vivo and we cannot conclusively determine that our observations would be similar if evaluating hip joint contact force in vivo. Fifth, as joint structure was not assessed beyond the hip joint in those in the asymptomatic groups, we cannot conclude that our observations are not in part attributable to the presence of radiographic alterations other joints. Finally, the sample size in this exploratory study was relatively small we did not have sufficient statistical power to account for the effect of sex. Sex differences have been seen particularly in the frontal plane moments of people with hip OA (Foucher, 2017). Observations from this study aim to inform hypotheses to be tested in larger studies and should not be considered conclusive.

In conclusion, we found evidence to suggest that the peak hip adduction moment and the internal hip rotation moment (peak and impulse) were lower in people with a combination of hip OA symptoms and radiographic disease. We also found that walking speed was significantly slower in people with mild radiographic disease, irrespective of the presence of symptoms, compared to asymptomatic OA-free controls. Future research is required to elucidate movement strategies among people with mild radiographic hip OA to identify potential treatment targets that alleviate symptoms and preserve the integrity of the joint structure.

Declaration of Competing Interest

The authors deny any financial or personal relationships that could bias this work.

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